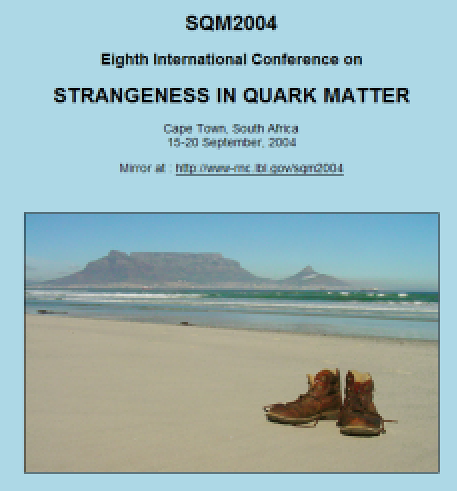
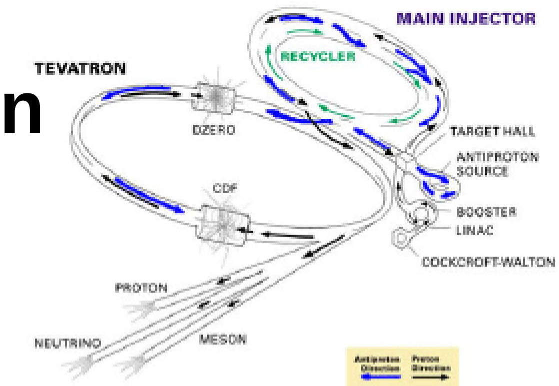


Fermilab's Accelerator Complex



Heavy Flavour Production at the Tevatron

G.Pauletta
(Univ. of Udine)

for the CDF & D0 collaborations

Will report on production of:

quarkonia

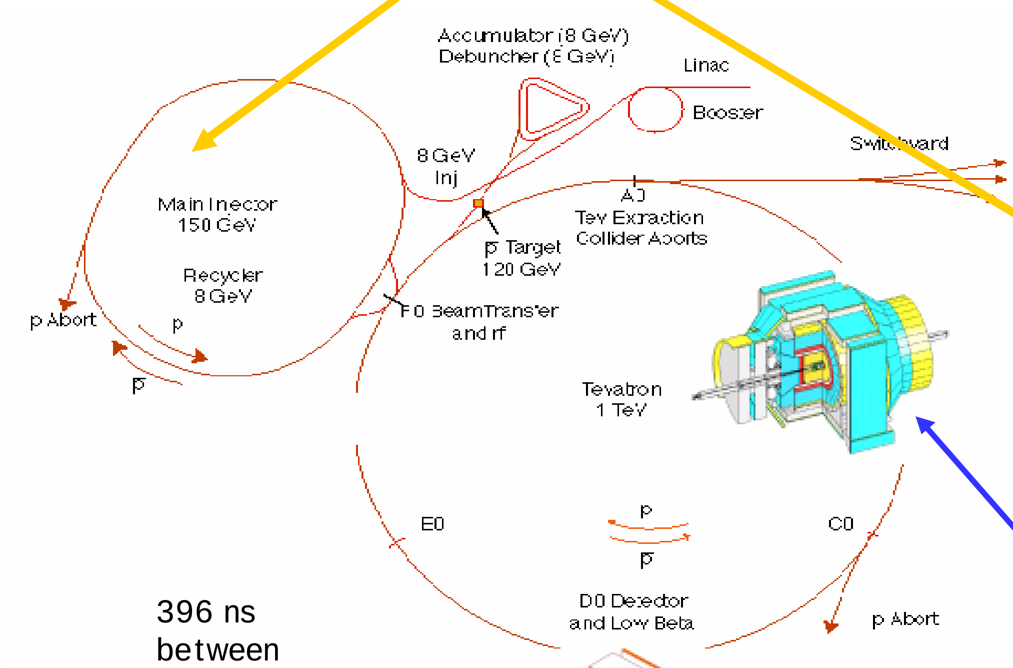
B Jets

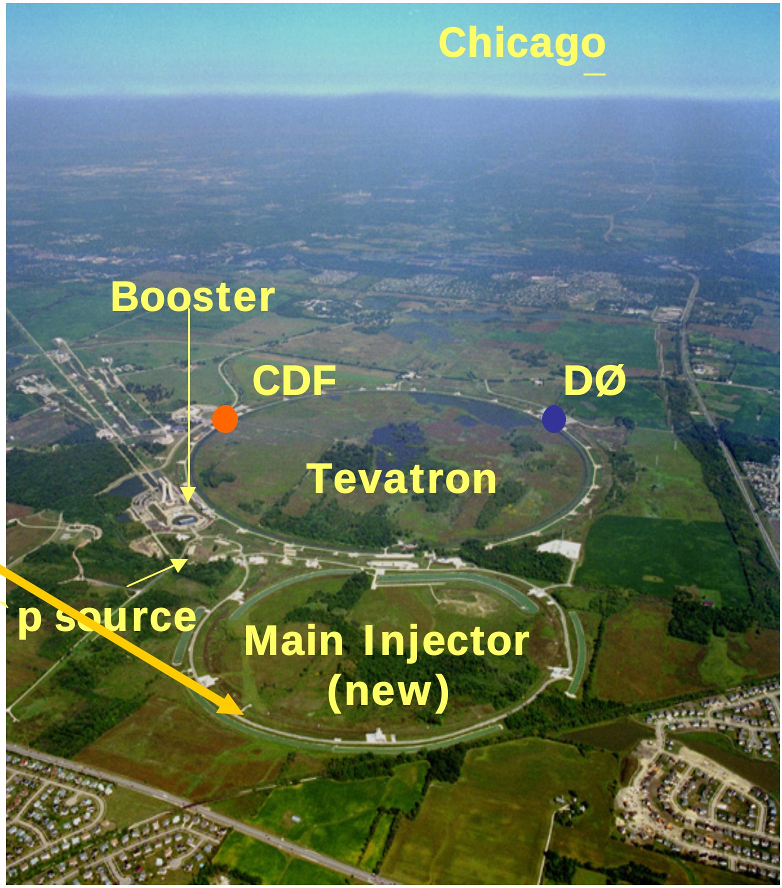
C and B mesons

top

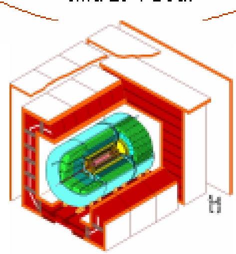
as measured at the tevatron in Run 2

Run II benefits from: the addition of a new 150 GeV injector and recycler

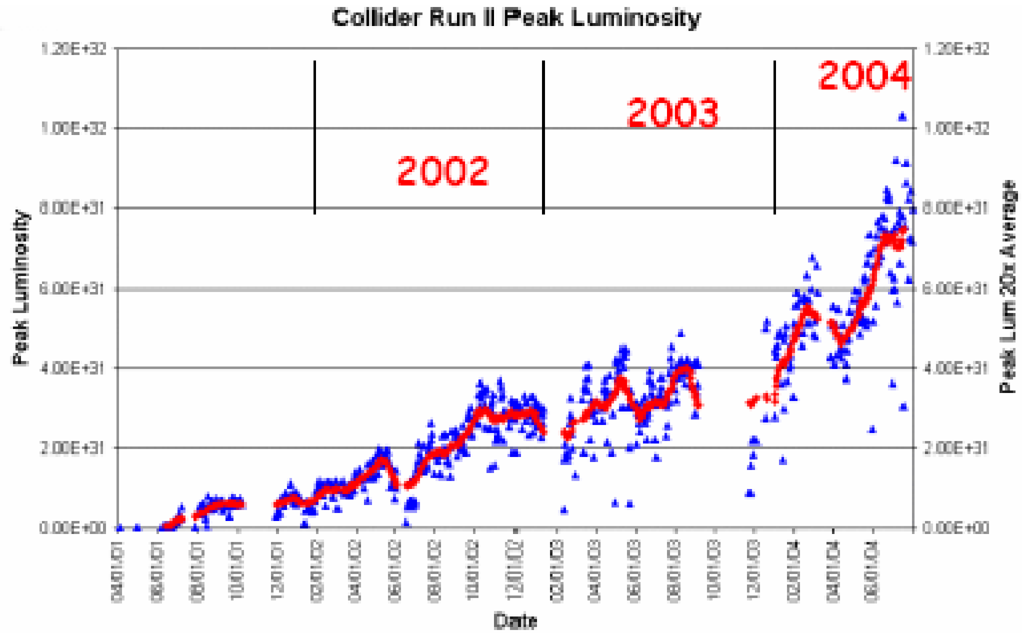




396 ns
between
collisions

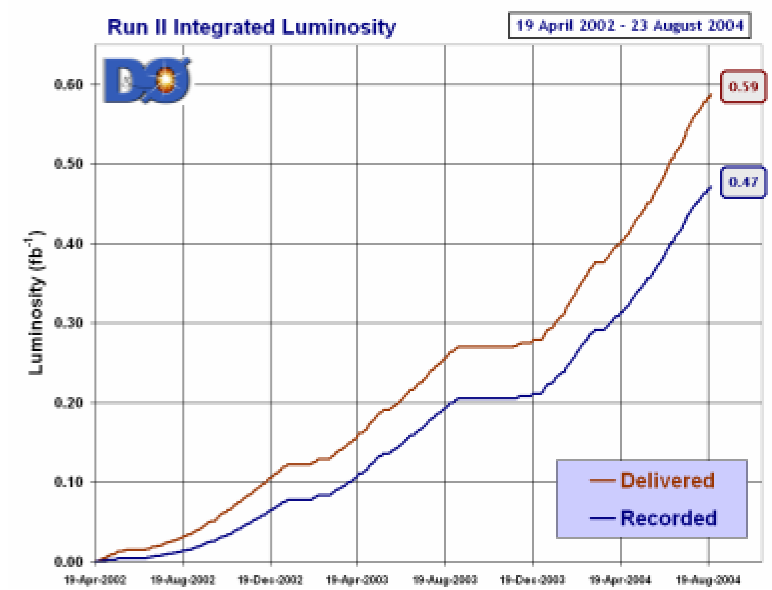


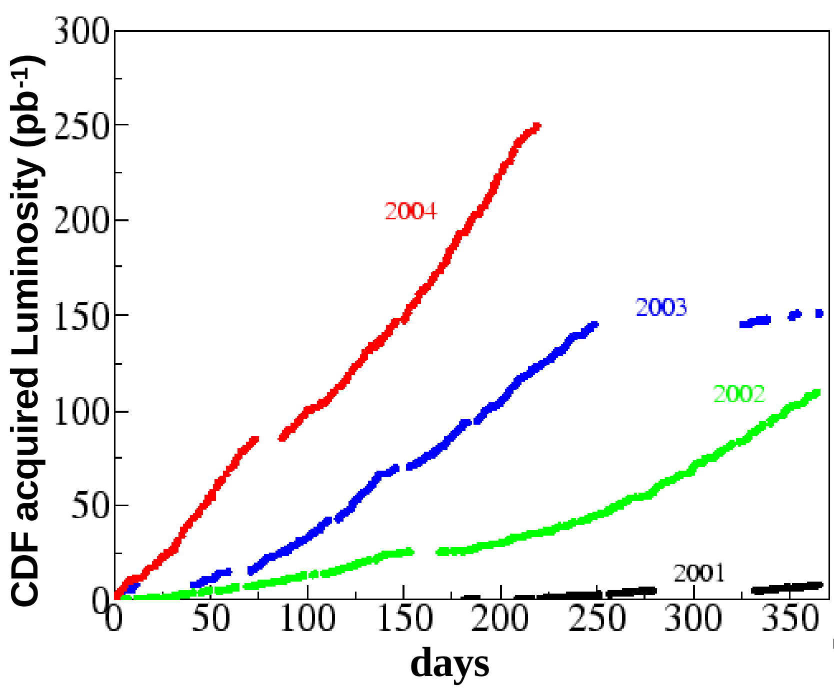
........and of
upgraded detectors



Luminosities make steady progress as tuning of the new accelerator components proceeds.

Peak luminosity so far: of 10^{32} $cm^{-2}s^{-1}$



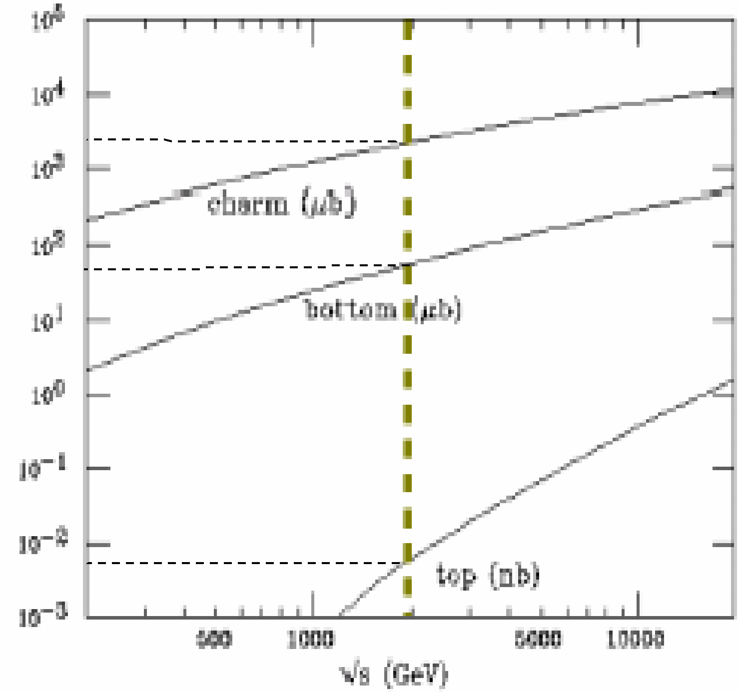


Efficiency of detectors is good

~ 450 pb^{-1} recorded.

< 150 pb^{-1} analyzed

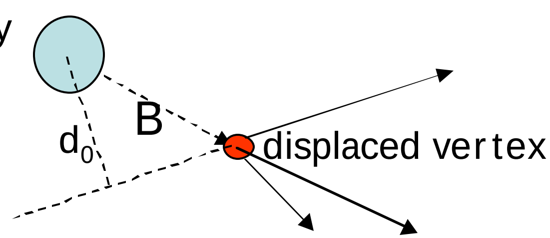
Charm and bottom are produced copiously ....
Much more than top and exotics but much less so than lighter flavours ($s_{tot} \approx 60 mb$).

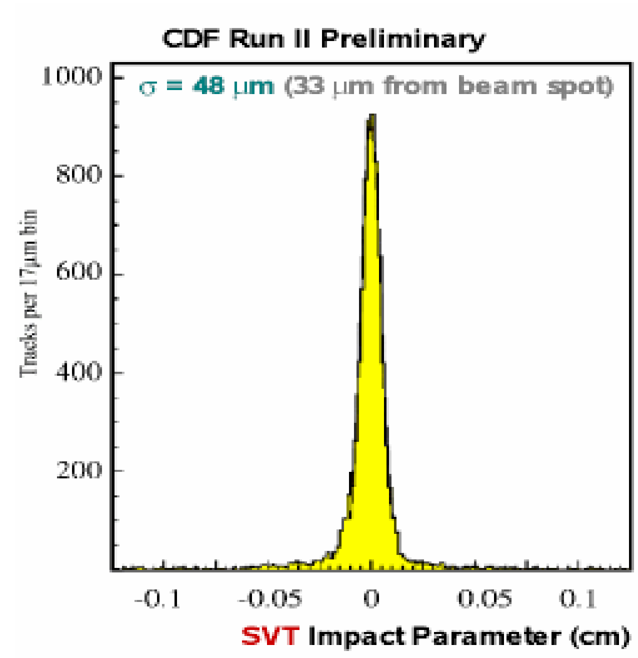


Problem:
Identify 1 B amongst > 10^3 QCD evts while leaving enough bandwidth for exotic triggers.

Imperative :
reduce background at trigger level
Increase trigger bandwidth
in order to avoid swamping rarer processes

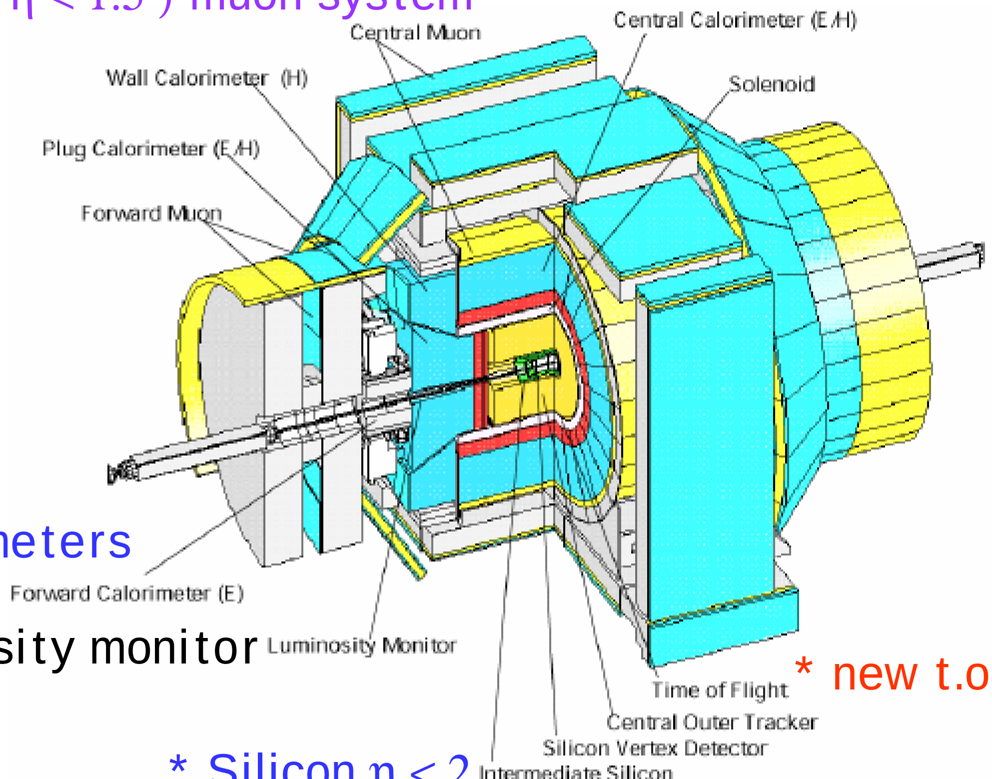
An **important contribution** comes from :
systems for triggering on displaced vertices.





Both detectors have been extensively upgraded to cope with increased rates

* Extended $(\eta < 1.5)$ muon system



* new forward calorimeters

* new luminosity monitor

* new t.o.f system for PID

* Silicon $\eta < 2$

* System (SVT) for triggering on displaced vertices

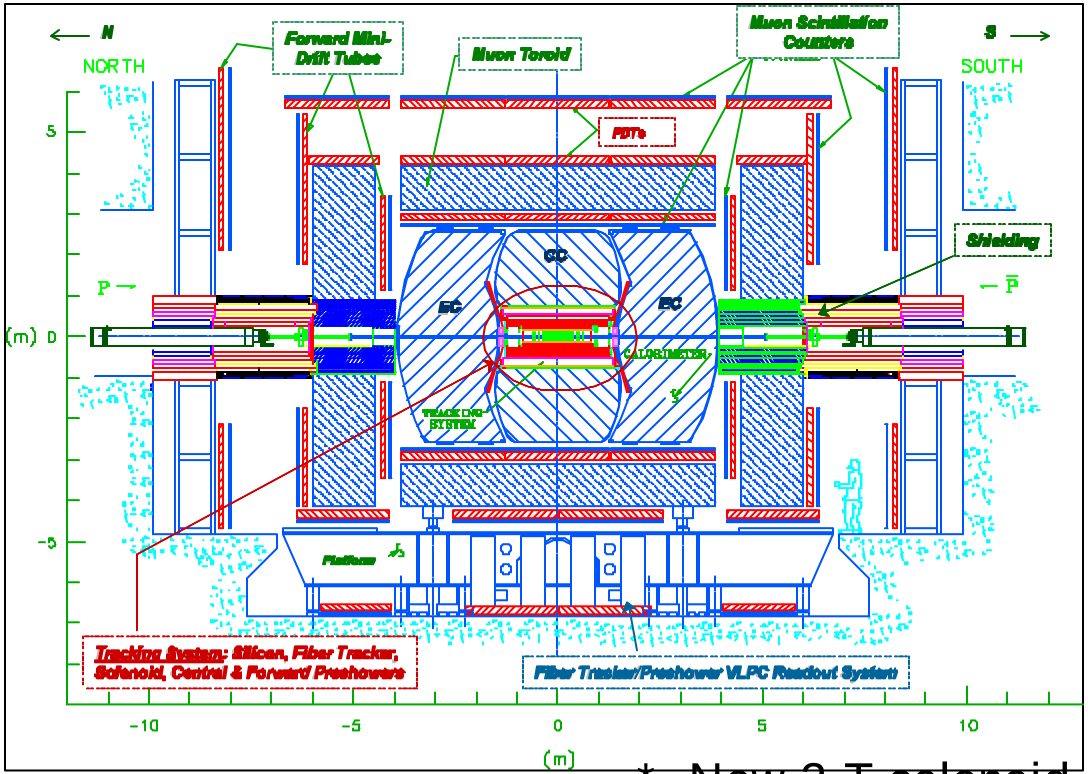
critical for heavy flavour

*New central tracker: drift chamber (COT)

+ new trigger and DAQ

- Muon coverage extended to $\eta < 2.2$
- Low P_t central muon scintillators
- New forward μ system

* New fiber central tracker



* New 2 T solenoid $\eta <$

- Silicon vertex ($\eta < 3$)
- New level 2 displaced vertex triggering system being commissioned

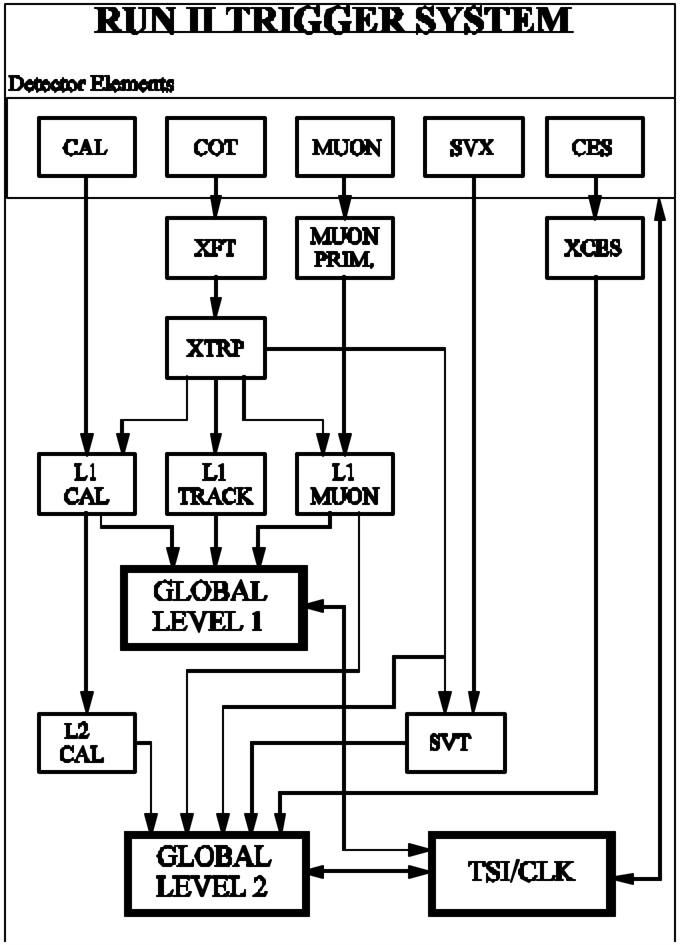
Tiggering schemes:

CDF:

Level 1: fast track trigger (XFT),
calorimeter E_T
muons
Level 2 add secondary vertex trigger (SVT)
jet clustering

e.g, for B at level 1:

* Lepton + displaced-vertex track:
$P_t(\mu, e) > 4$ GeV/c, $d_0 > 120\ \mu$m, $P_t(T) > 2$ Gev/c
* two displaced-vertex tracks:
$Pt(T) > 2$ Gev/c, $d_0 > 120$ mm, $\Sigma P_T > 5.5$ GeV/c
* Two muons :$Pt(\mu) > 2$ Gev/c



D0:

Similar to CDF but
Muon coverage larger
Displaced – vertex track trigger still
being commissioned

level	rate
Bunch crossing	2.5 MHz
Level 1	30 KHz
Level 2	400 Hz

Heavy Quarkonium Production

* Run I data were in severe disagreement with early theoretical predictions (only color singlet production).

* More recent theories better, e.g. within Non –Relativistic QCD (NRQCD) , the Color octet model allows for production of $b\bar{b}$ in the octet state → singlet by soft gluon emission. Fix the discrepancy -- but at the cost of introduction of phenomenological parameters.

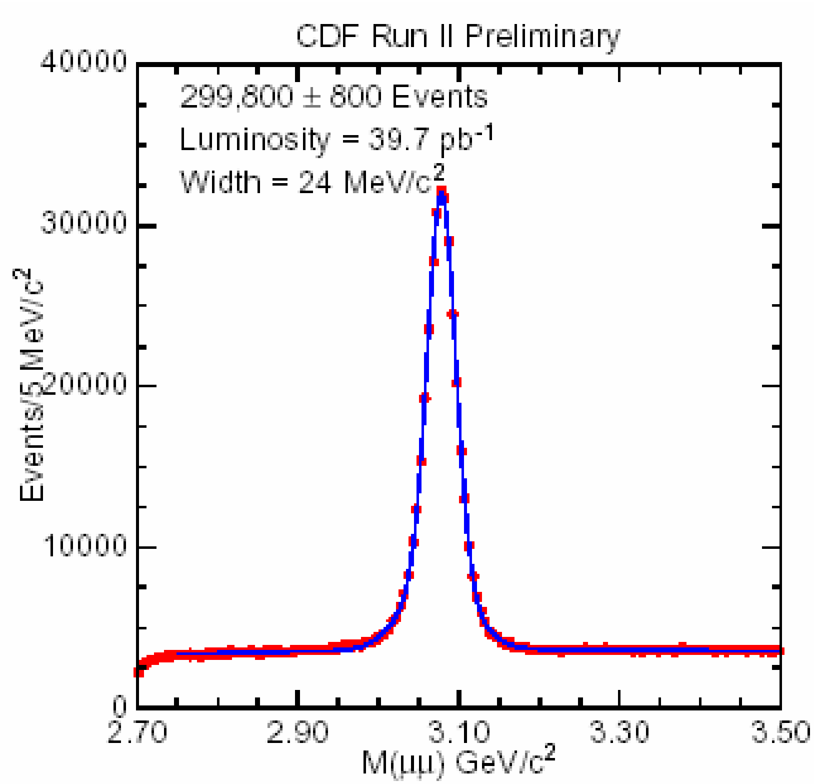
Resolution of this situation requires extended and diverse measurements .

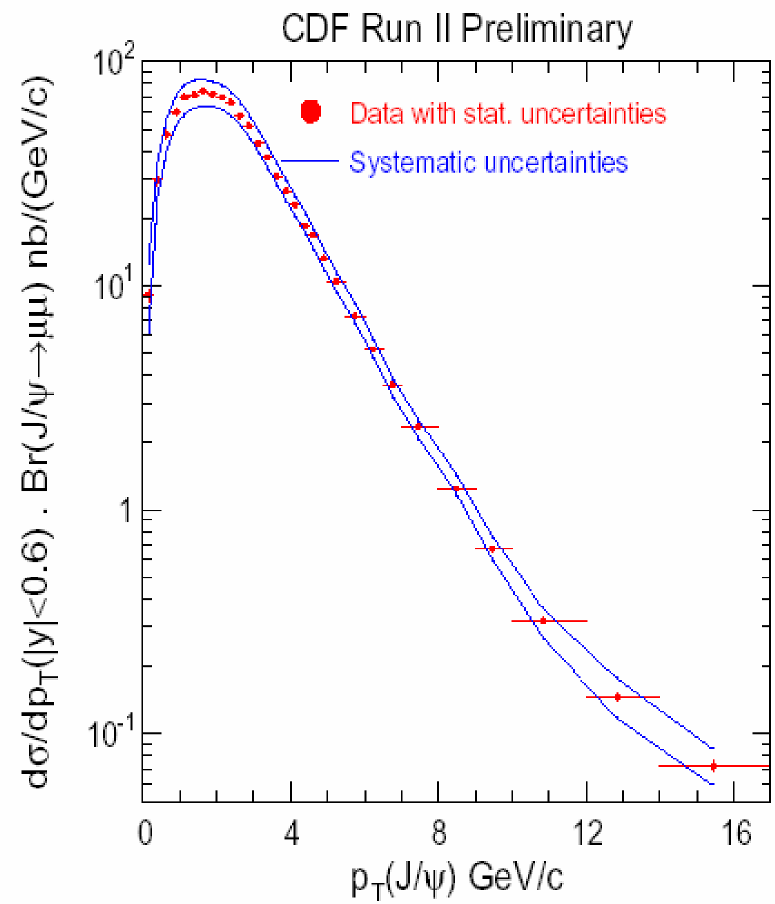
$J/\Psi \rightarrow mm$ is easy to trigger on and X-section and polarization measurments are a good testing ground for the current QCD models.

So studies of charmonium production were amongst the first to be conducted after the Run II startup.

90% of the x-sect lies below the Run I P_t threshold, so a special effort was made to reduce this threshold.

Charmonium production

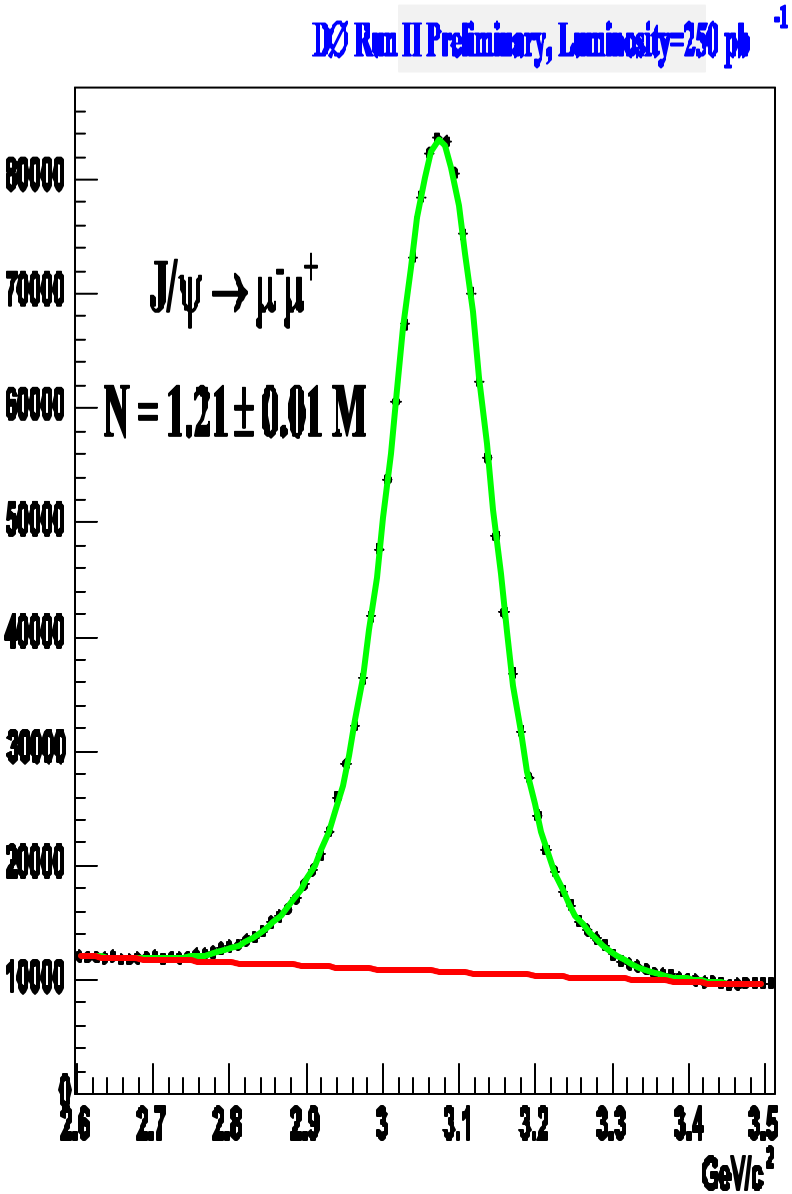




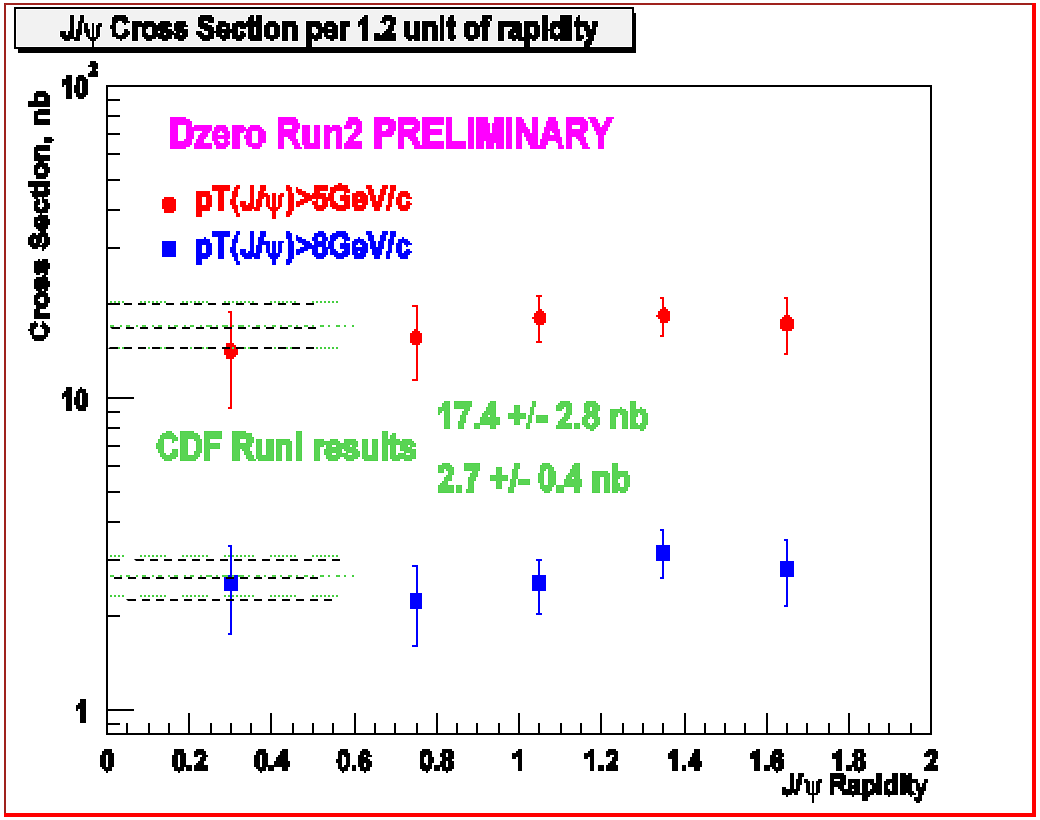
Inclusive diff. x-sect for rapidity < 0.6

Improved dimuon trigger with P_T threshold of 1.5 GeV/c . This includes J/Psi with momenta extending down to 0 GeV/c. Taking the kinematic/detector) acceptance into account, one measures the:

total inclusive J/Ψ x-sect: $s\left(p\bar{p} \to J/\Psi, |y(J/\Psi) < 0.6\right) = 4.08 \pm 0.02(stat) \pm 0.36(syst)\ mb$

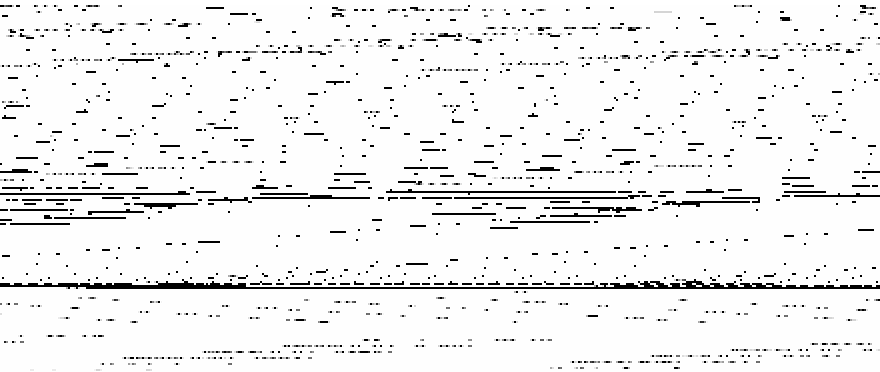


Exploiting their large muon coverage, D0 has measured the x-sect as a funtion of rapidity.

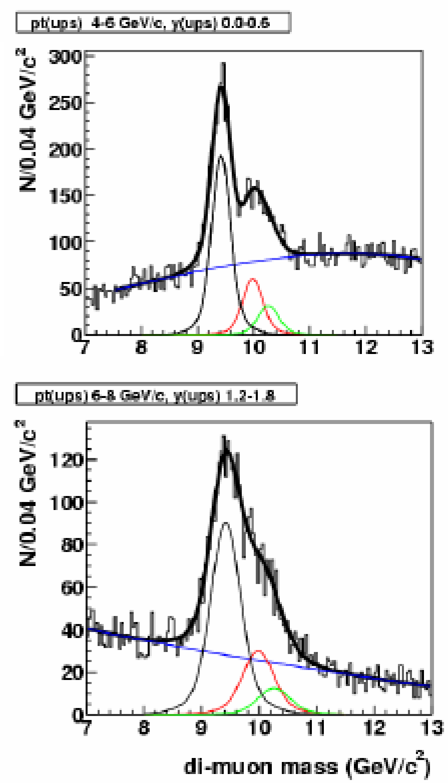


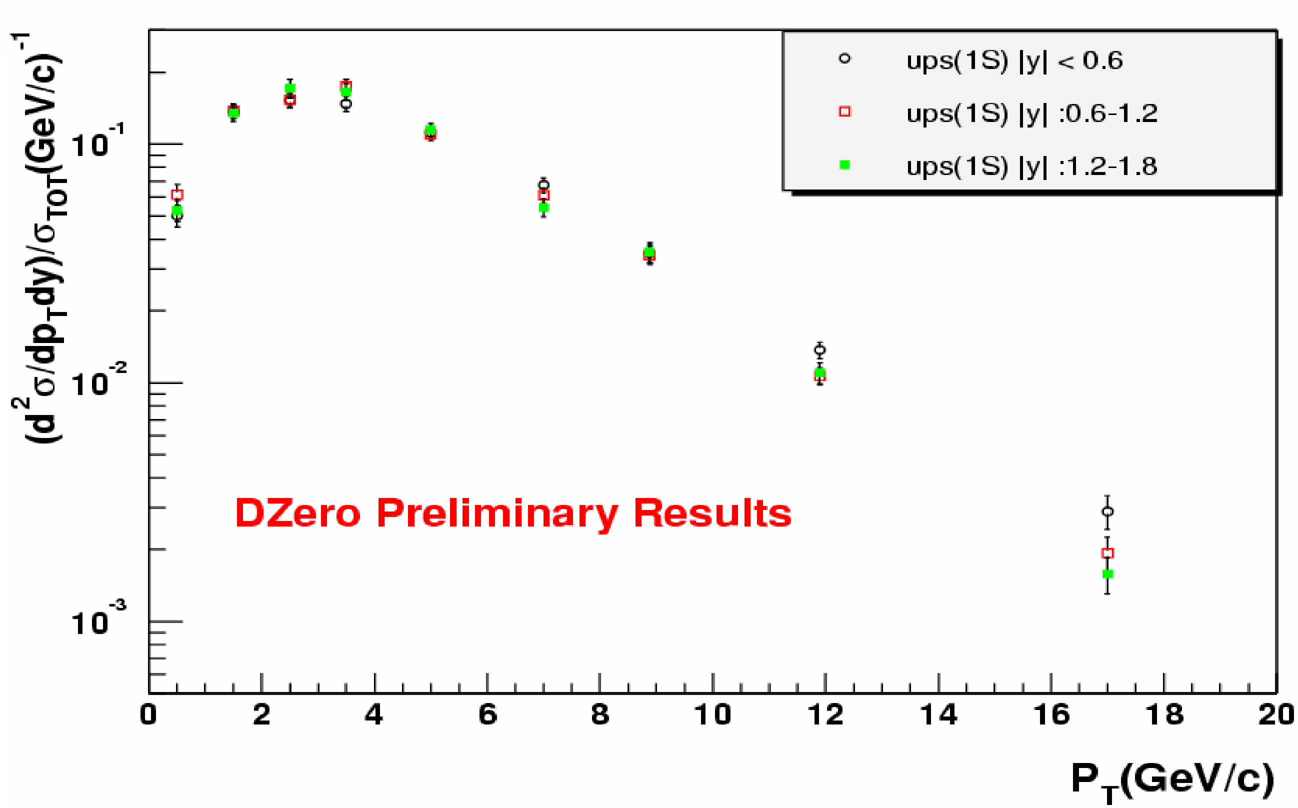
Polarization measurements have yet to be reported

Upsilon production:



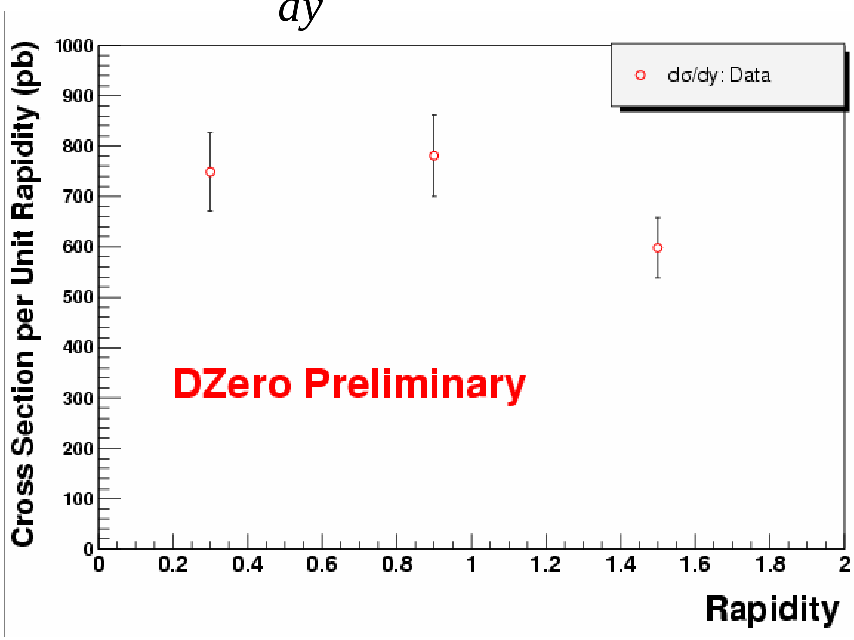
Using an integrated luminosity of 159pb^{-1}, D0 measures inclusive x-sect for production of the $\Upsilon(1S)$ bottonium state

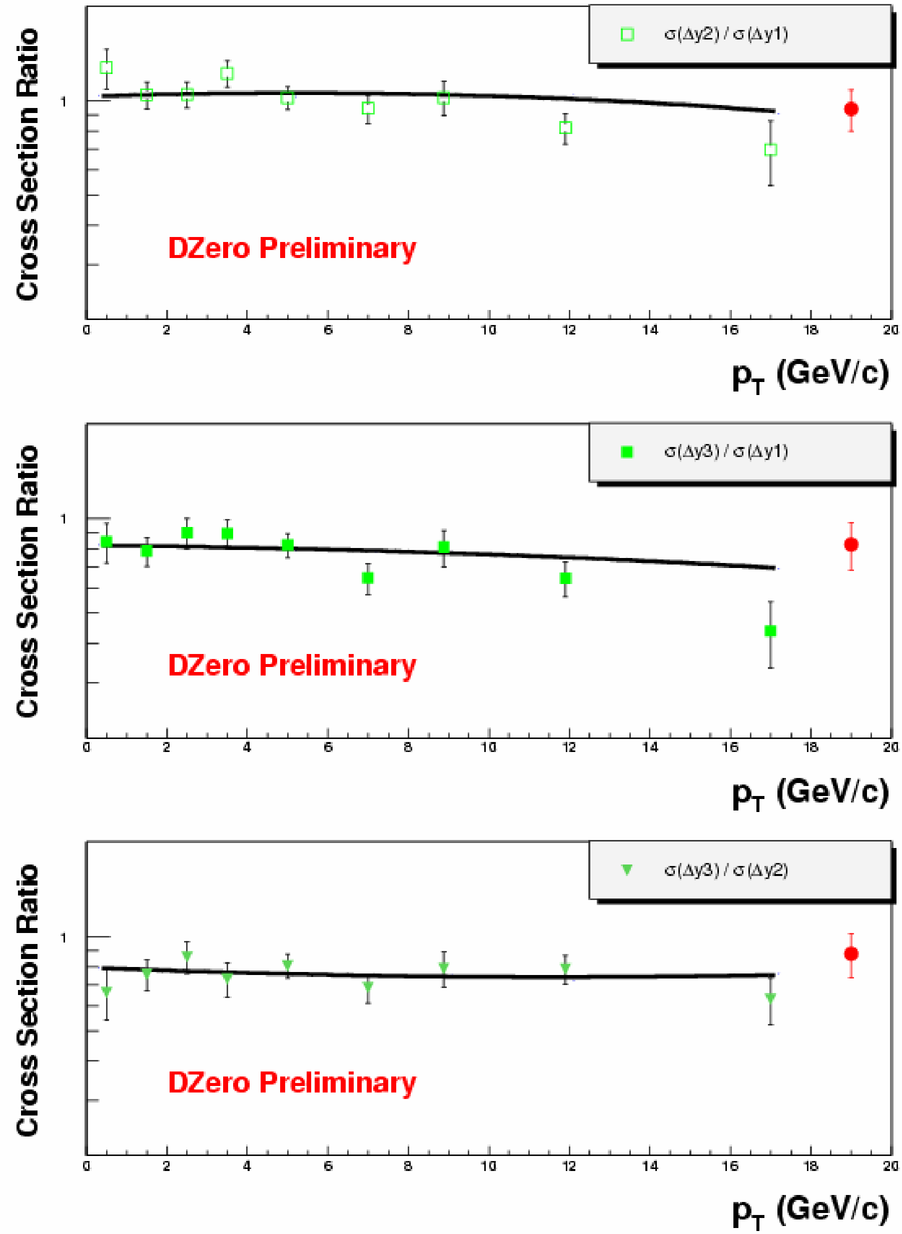




* 3 rapidity (y) ranges
* first measurment at large y
* little dependence on y

$$\frac{ds}{dy} \bullet Br(Y \to mm)$$



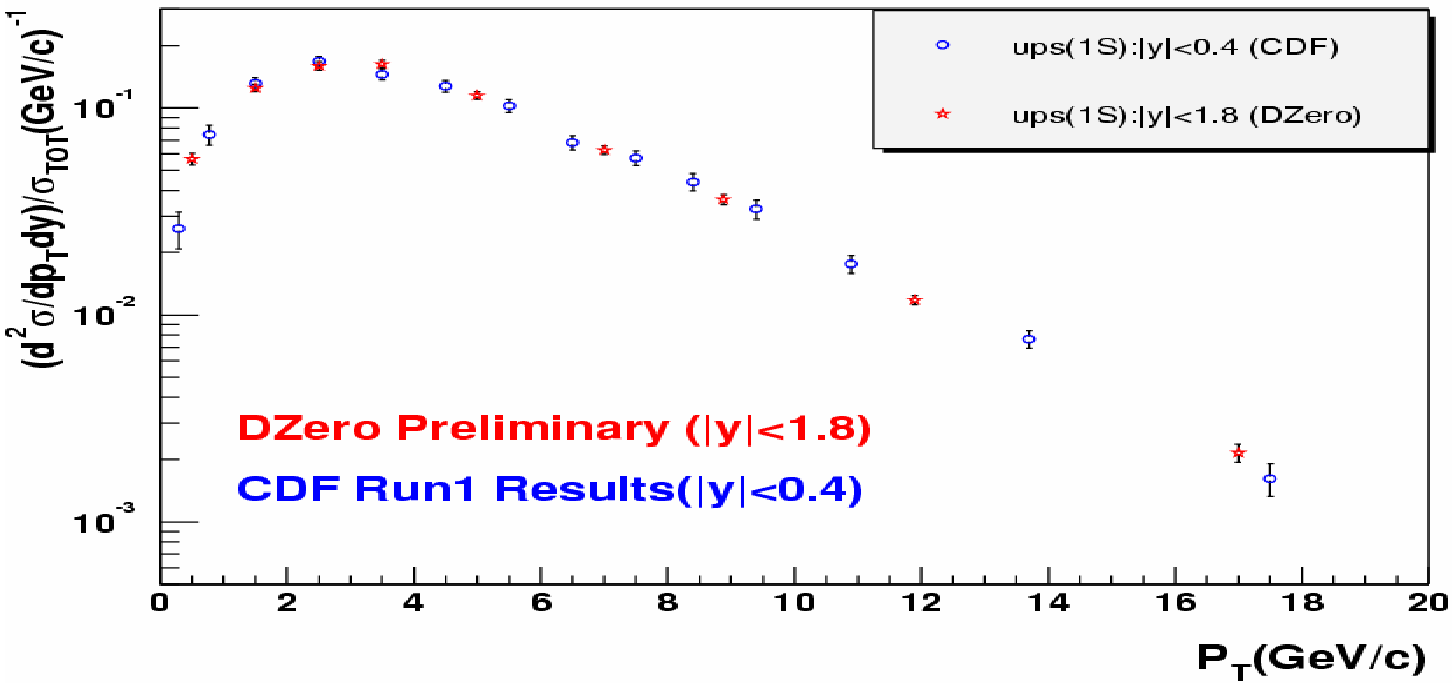


Ratios consistent with Pythia

Comparison with CDF (RunI) data:

$s \cdot BR(\Upsilon \to m^+m^-)(|y| < 0.4) = 680 \pm 15(stat) \pm 18(syst) \pm 26(lum)$ at CDF for $\sqrt{s} = 1.8TeV$

$s \cdot BR(\Upsilon \to m^+m^-)(|y| < 0.6) = 749 \pm 20(stat) \pm 75(syst) \pm 49(lum)$ At D0 for $\sqrt{s} = 1.96TeV$



* Color octet model predicts an increase in transverse polarization with increasing PT

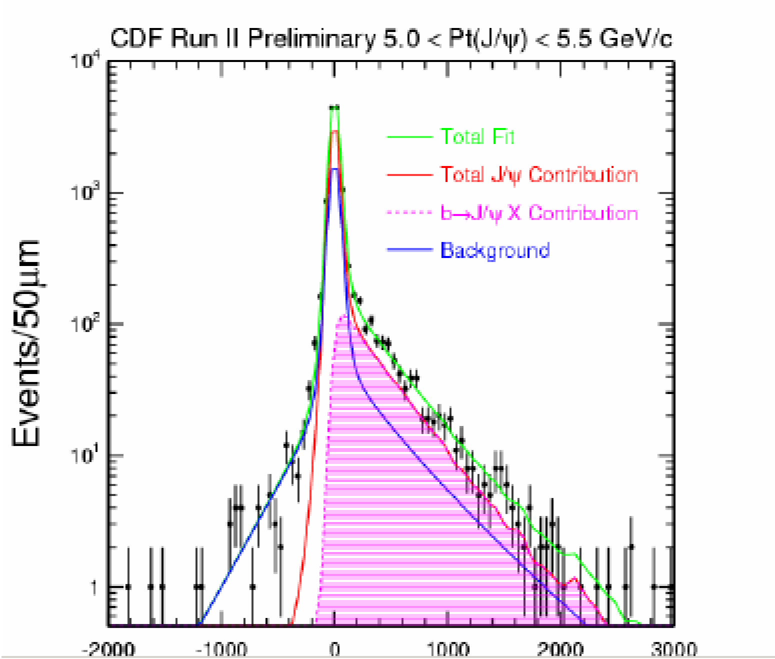
* Results of polarization measurements are not yet available

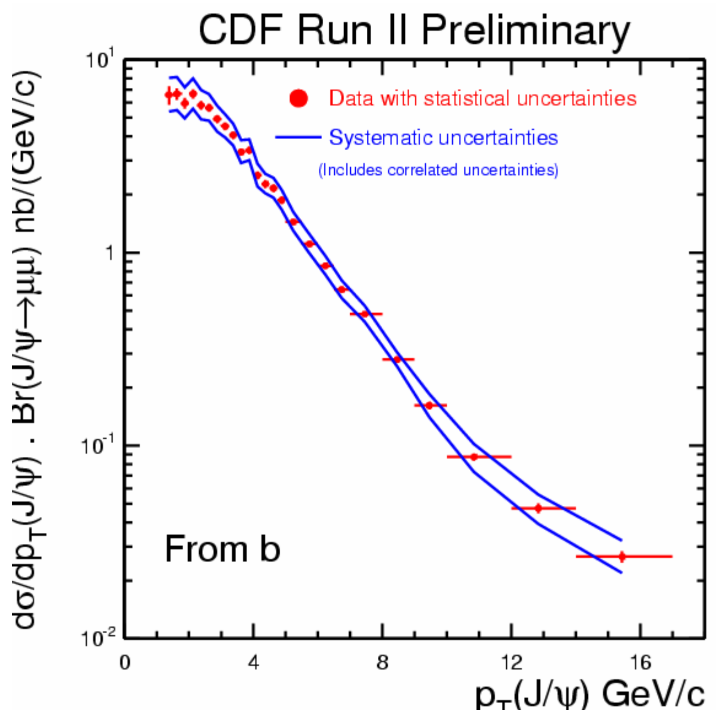
B hadron production

From J/y inclusive x-sect:

A considerable fraction of J/y comes from B-hadron decay. Since this contribution has a long decay time relative to prompt J/Y production,

CDF extracts B-hadron contribution to the J/Psi x-sect using the displaced vertex distribution

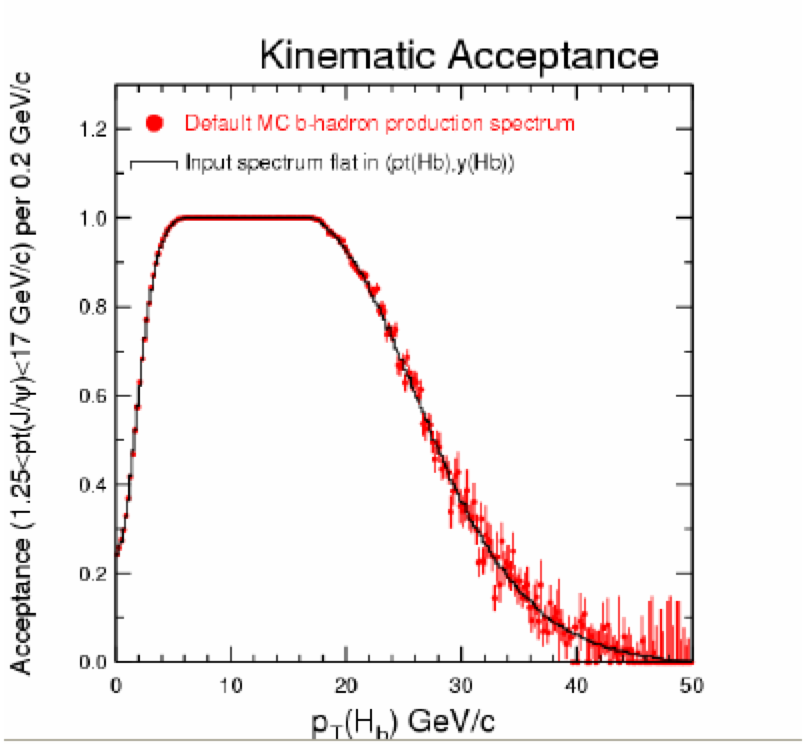


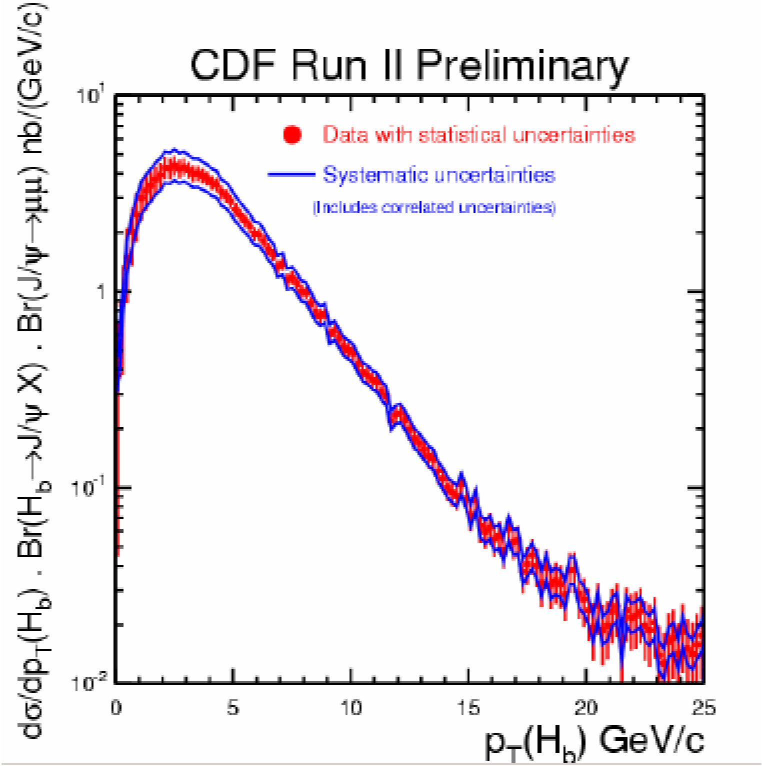


$$s\,(p\bar{p} \to H_b X, p_T(J/\Psi) > 1.25GeV/c, |y(J/\Psi)| < 0.6) \cdot Br\left(H_b \to J/\Psi\right) \cdot Br\left(J/\Psi \to mm\right) =$$

$$19.4 \pm 0.3(stat)^{+2.1}_{-1.9}(syst)nb$$

Then, using the well-known kinematics of charmonium produced in B meson decays, the calculated acceptance and known branching ratios,the production x-sect for b hadrons (H_b) is extracted.





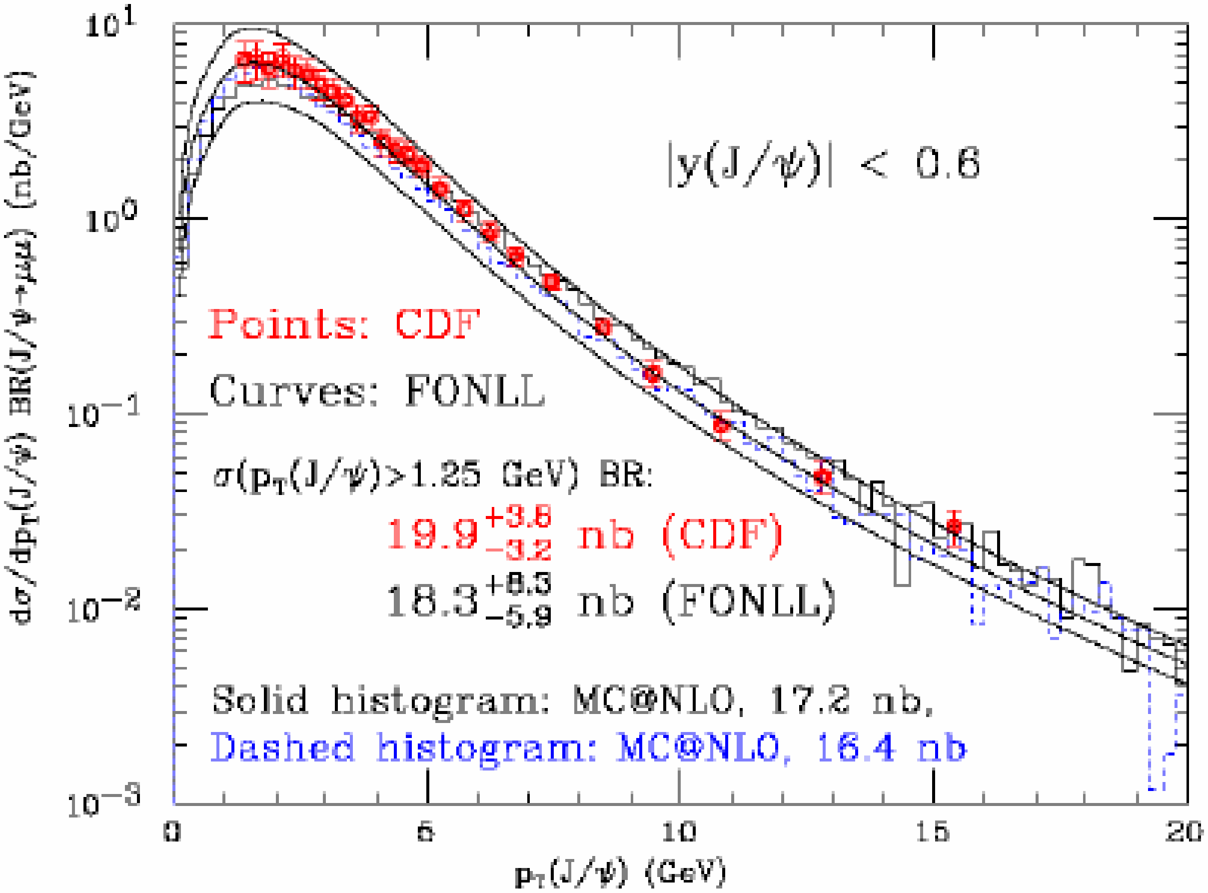
Integrating and accounting for branching fractions, they obtain:

$$s\left(p\bar{p} \to bX, |y_b| < 1\right) = 17.6 \pm 0.4(stat)^{+2.5}_{-2.3}(syst)\ mb$$

for the total inclusive b-hadron x-sect

Very good agreement with FONLL (CTEQ6M)theory

(Cacciari,Frixione, Mangano, Nason & Ridolfi, JHEP07, 2004, 033)



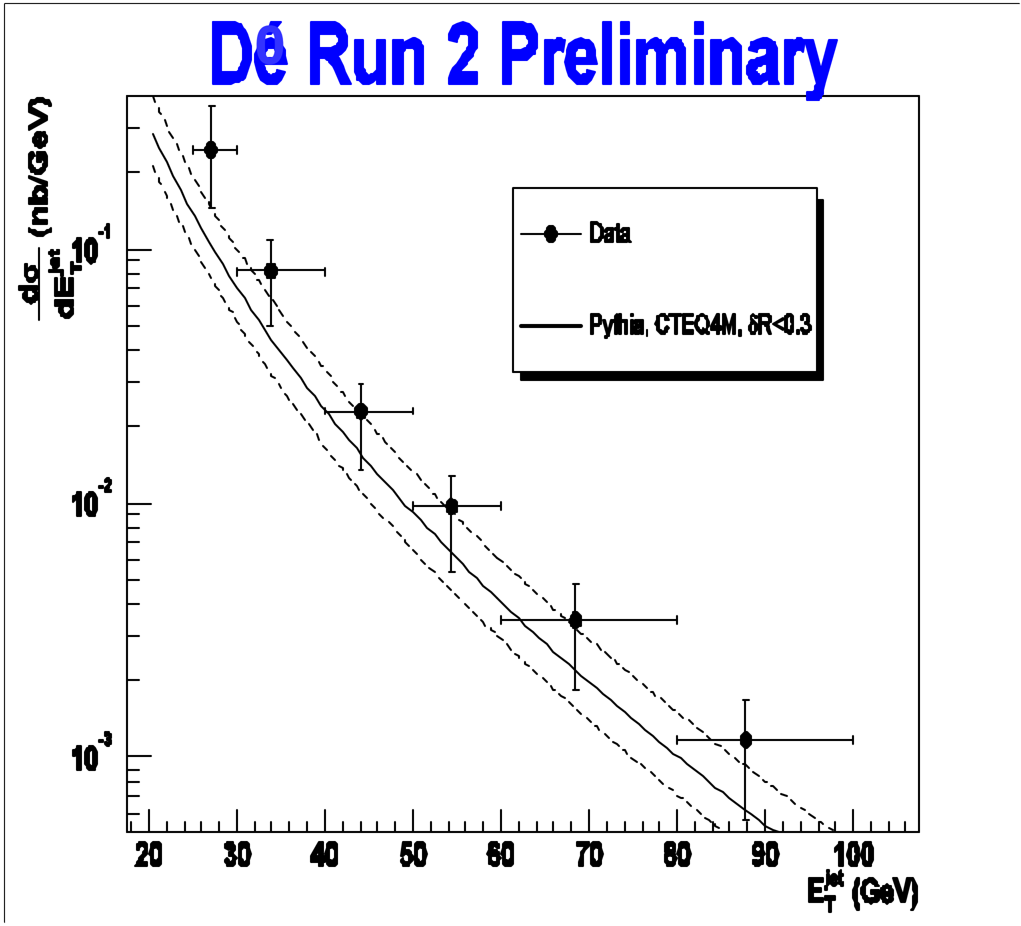
b jet production

* Direct measurement of b – jet production x-sect extracted at D0 from 3.4 pb^{-1} of QCD data

* b-jet identified by associating a muon track with the jet:

  distr. of transverse μ momentum w.r.t. combined μ+jet momentum is compared to MC and b.g. templates.

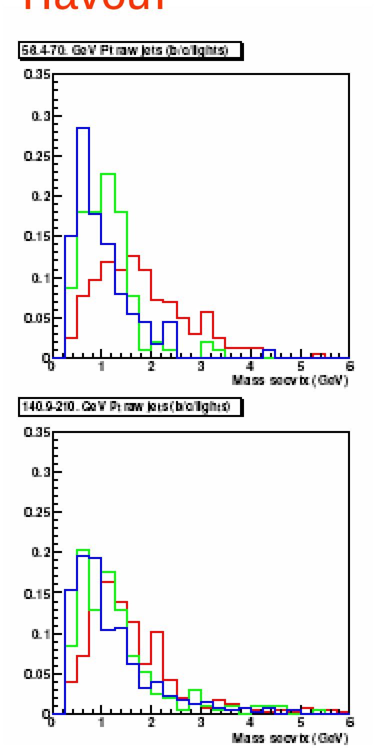
* Agrees with Run I data



Compared with theory (Pythia)

CDF uses displaced vertex tagging of to extract b–quark x – sect from 150 pb-1 QCD data : 30 GeV/c < P_t < 210 GeV/c, 0.1 < η < 0.7

Reconstructed secondary vertex mass depends on flavour



Templates used to Extract b-quark fraction

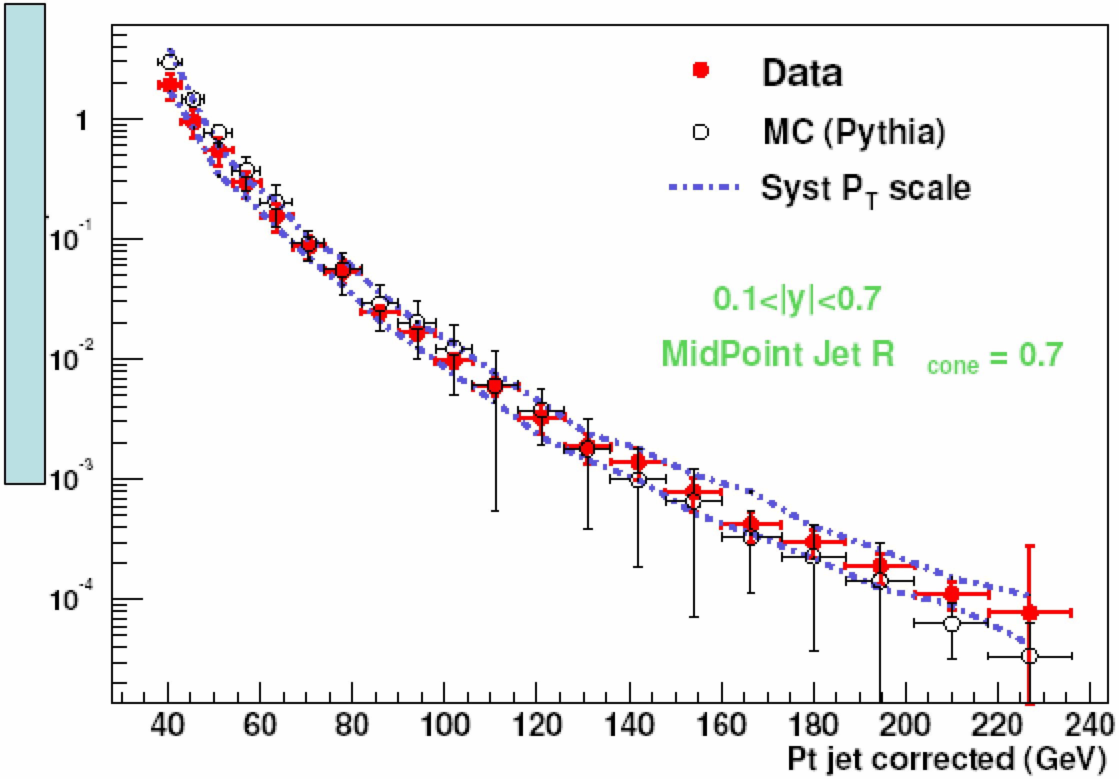
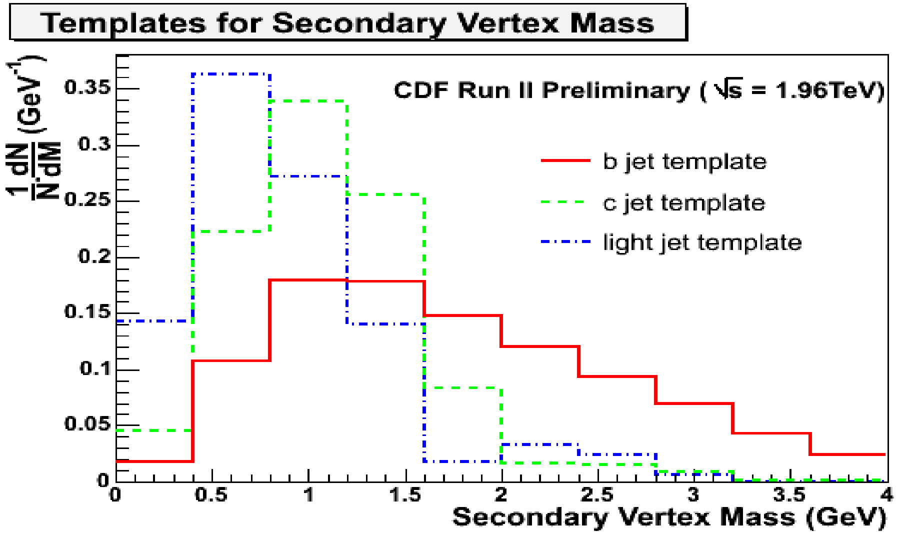
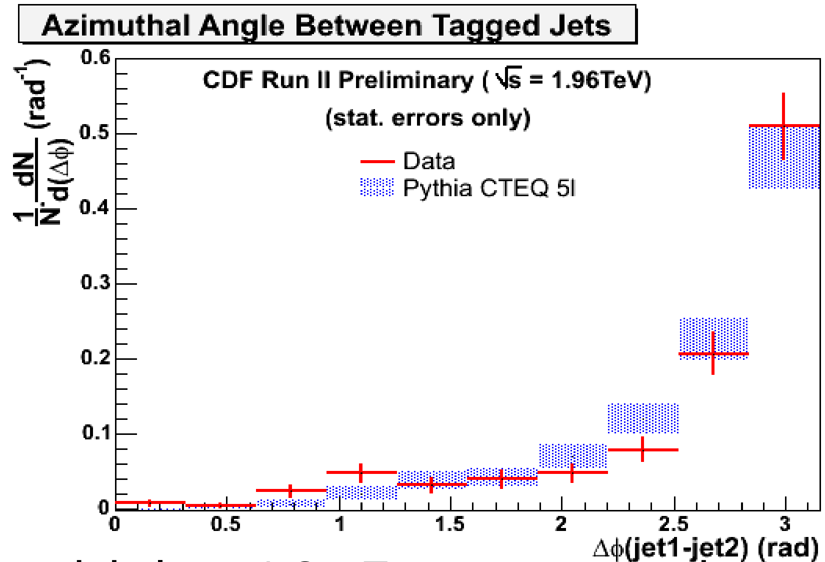


Figure 17: b-jets cross section for data and MC as a function of average corrected jet P_T. Systematic uncerainty due to absolute energy scale is also shown.

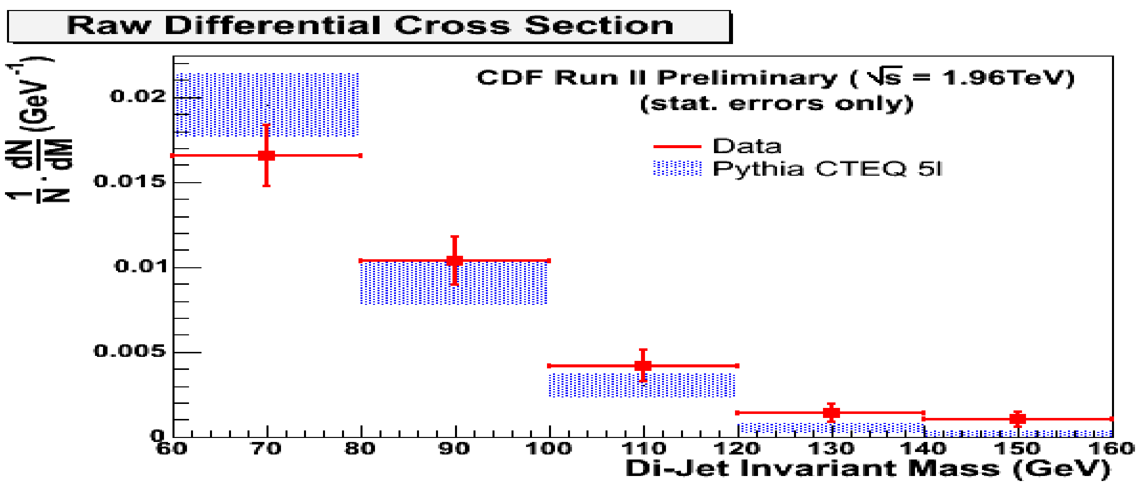
* Secondary vertex mass distribution templates also used to extract b – dijet xsect . → Flavour selection favours back-to-back jets





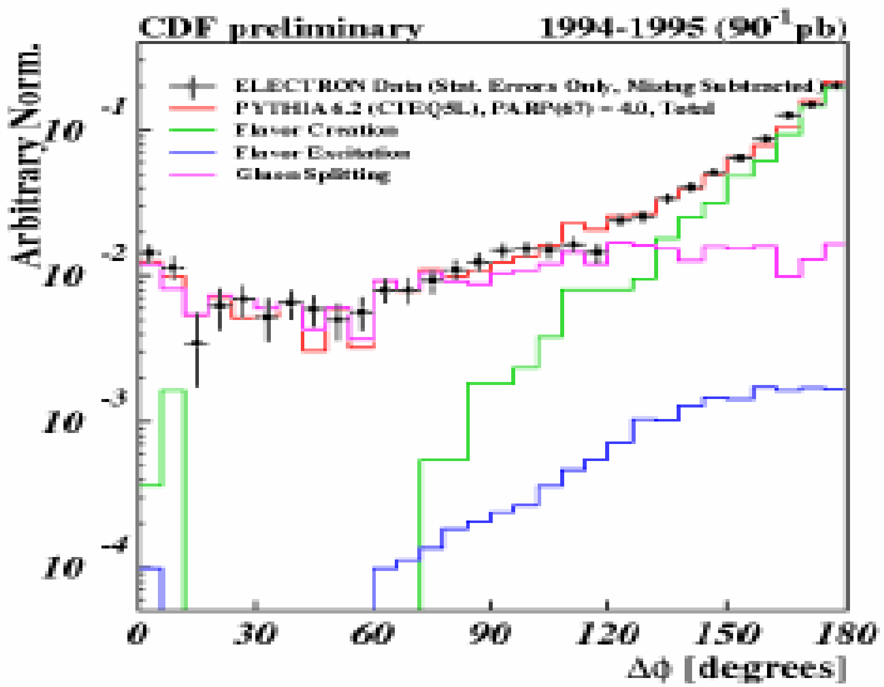
Require two secondary vertex – tagged jets with $|\eta| < 1.2$. For one tagged jet, E_T(corr) > 30 GeV, for the other, raw E_T > 10 GeV

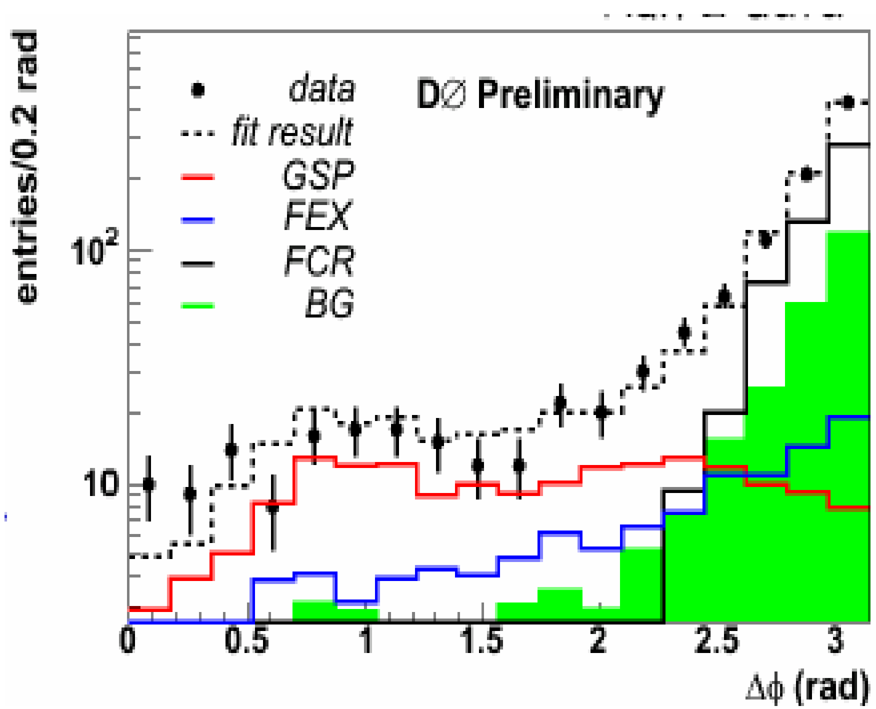
Relative units

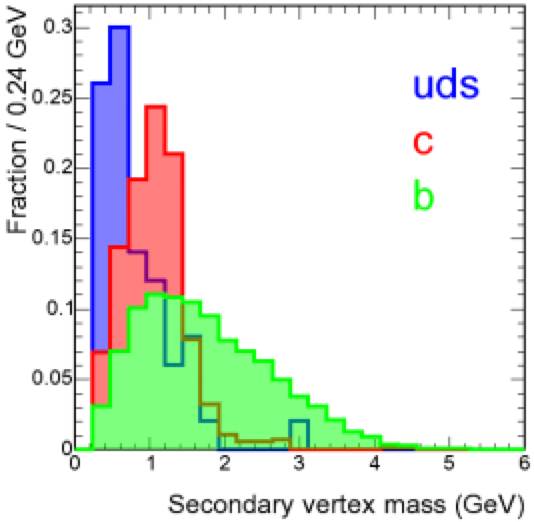


Jet – jet correlations may help to understand production mechanism:

Besides LO flavour creation, evidence of NLO contributions such as
* flavour excitation
* gluon splitting



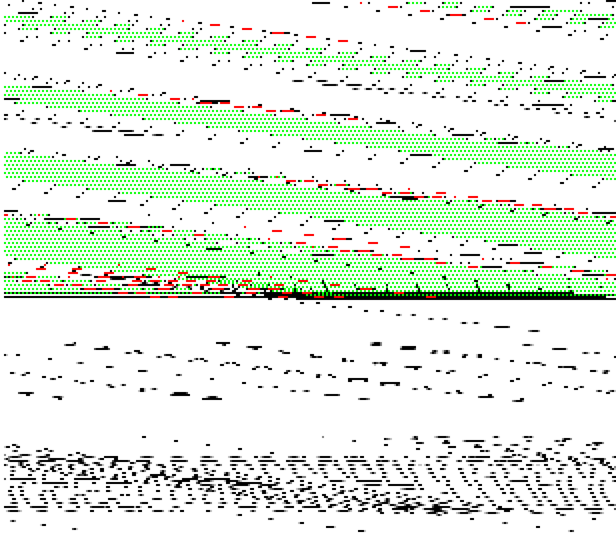


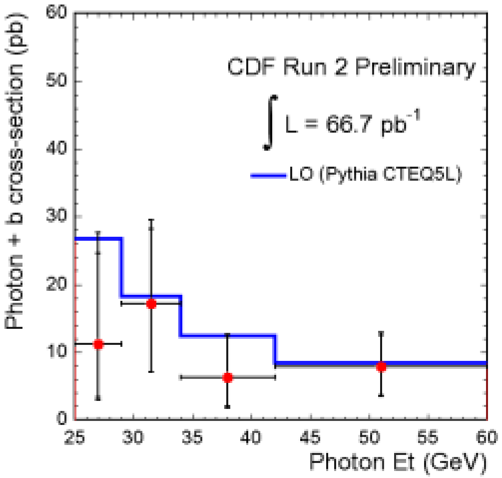


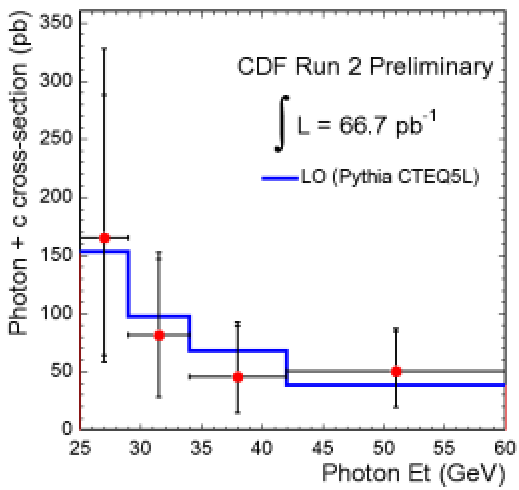
g + b-jets

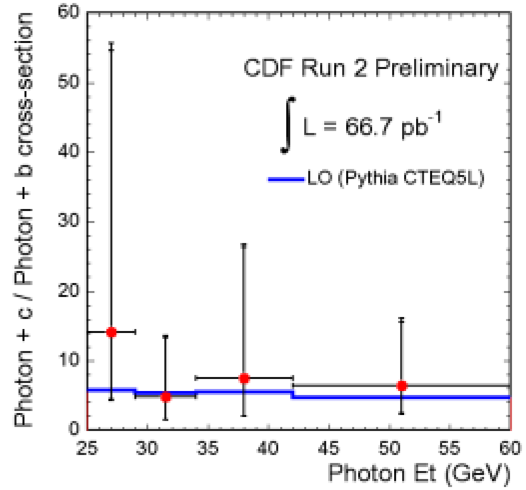
Secondary vertex reconstruction used also exploited to investigate γ+ b-jet production at CDF

$E_t(\gamma) > 25$ GeV





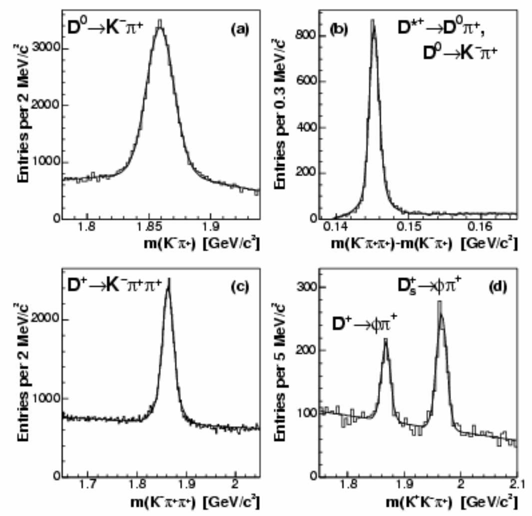




$\sigma(b + \gamma) = 40.6$ +/- 19.5 (stat.) +7.4 -7.8 (sys.) pb

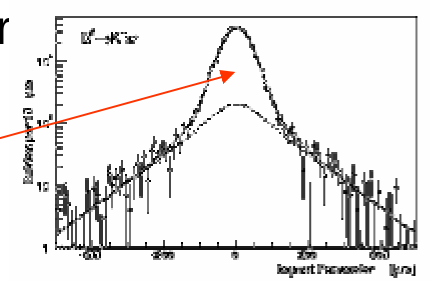
$\sigma(c + \gamma) = 486.2$ +/- 152.9 (stat.) +86.5 -90.9 (sys.) pb

Charm production

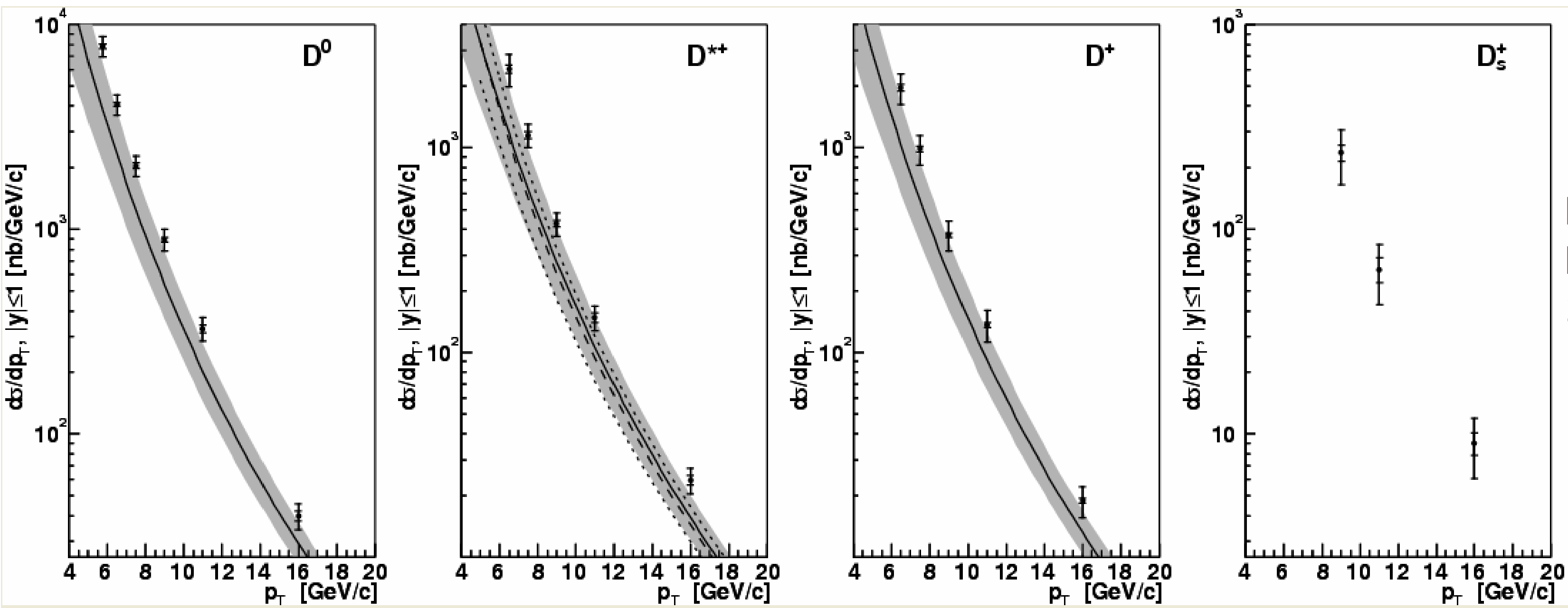


CDF has measured prompt charm meson production x-sect from 5.8 pb^{-1} data with displaced vertex trigger

Typically 80%



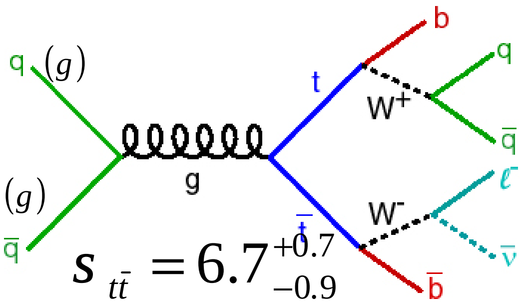
	P_t thr. GeV/c	s μb
D^0	5.5	**13.3±0.2±0.5**
D1 *+	6.0	**5.2±0.1±0.8**
D^+	6.0	**4.3±0.1±0.7**
D_s	8.0	**0.75±0.05±0.22**



Published PRL 91, 241804,04

Theory: Cacciari & Nason, JHEP 0309, 2003,006 and B.A.Kniel, private comm (dashed curve, D^{*+})

top pair production

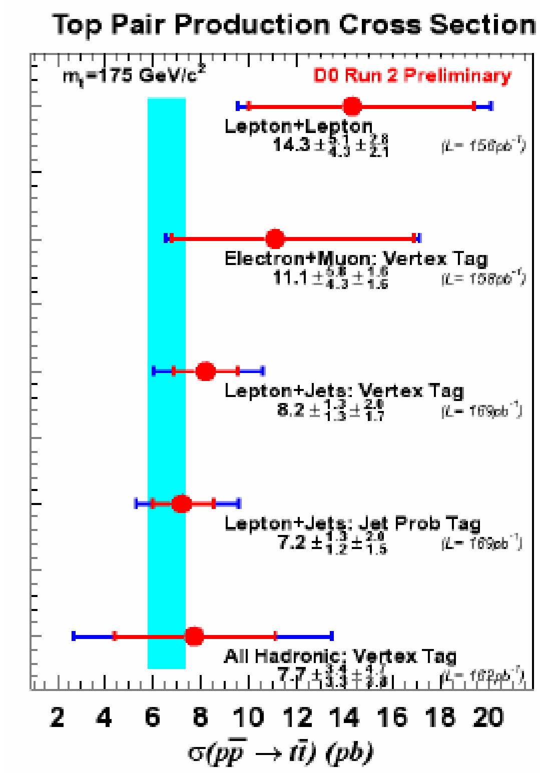


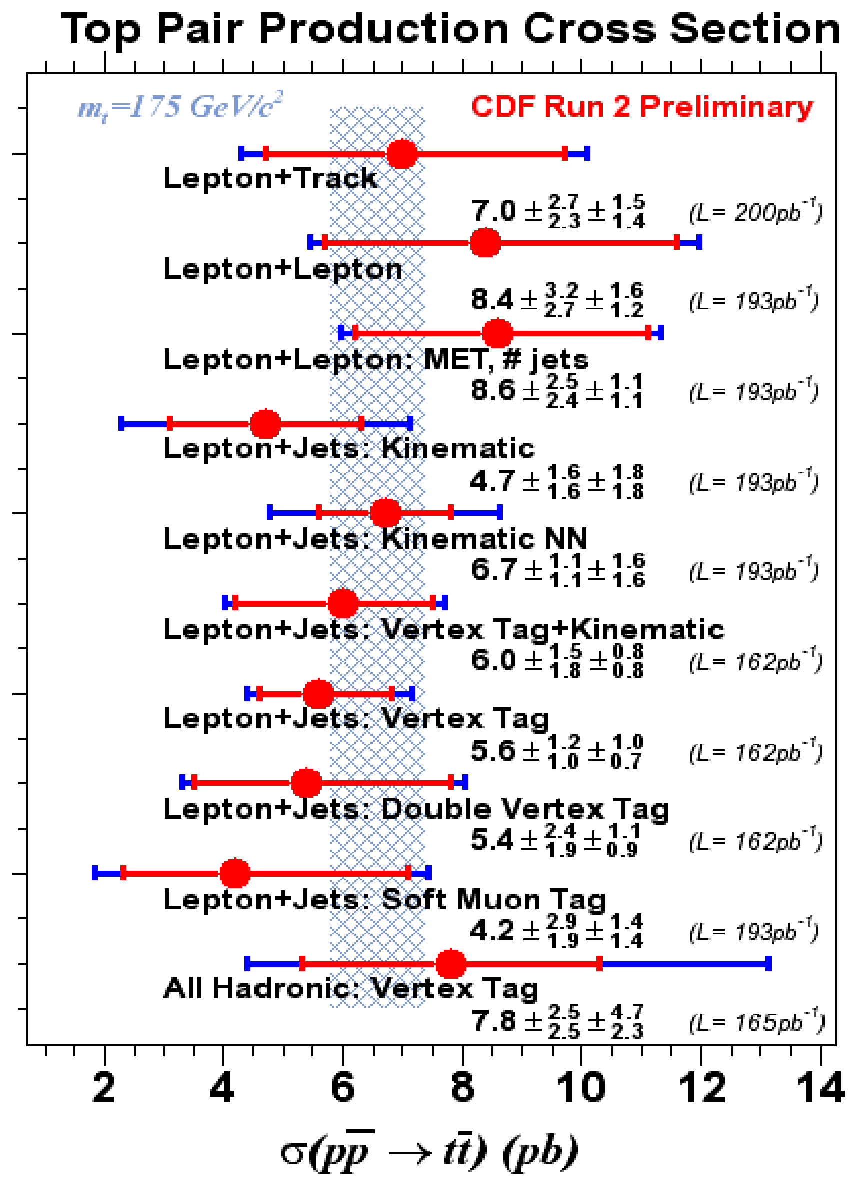
$$\sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9}$$

15% from gg
85% from qq

Cacciari *et al., JHEP 0404-068*, 424 (2004)
Kidonakis and Vogt, *Phys. Rev.* **D68**, 114014 (2003)

* Trigger on high P_t lepton or multijets
* BG is main problem
* various ways of enhancing signal/bg leads to different analyses





Conclusions

Displaced vertex triggers have had a drammatic impact data quality

New and less ambiguous data + improved theory -> better agreement.

However, much of the improvement depends on phenomenological parameters which will require exhaustive testing.

New data is on the way (e.g.polarization measurements) the scope of such measurements will increase with the luminosity.